Journal of Forestry Research (2013) 24(2): 205–216
DOI 10.1007/s11676-013-0346-9

ORIGINAL PAPER

Vegetation-environment relationships in the forests of Chitral district Hindukush range of Pakistan

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Received: 2012-03-02; Accepted: 2012-04-15

Abstract: We investigated the composition of plant communities to quantify their relationships with environmental parameters in the Chitral Hindukush range of Pakistan. We sampled tree vegetation using the Point Centered Quarter (PCQ) method while understory vegetation was sampled in 1.5-m circular quadrats. *Cedrus deodara* is the national symbol of Pakistan and was dominant in the sampled communities. Because environmental variables determine vegetation types, we analyzed and evaluated edaphic and topographic factors. DCA-Ordination showed the major gradient as an amalgam of elevation (p<0.05) and slope (p<0.01) as the topographic factors correlated with species distribution. Soil variables were the factors of environmental significance along DCA axes. However, among these factors, Mg^{2+}, K_+ and N^{2+} contributed not more than 0.054% 0.20% and 0.073%, respectively, to variation along the first ordination axis. We conclude that the principal reason for weak or no correlation with many edaphic variables was the anthropogenic disturbance of vegetation. The understory vegetation was composed of perennial herbs in most communities and was most dense under the tree canopy. The understory vegetation strongly regulates tree seedling growth and regeneration patterns. We recommend further study of the understory vegetation using permanent plots to aid development of forest regeneration strategies.

Keywords: environmental relationship; multivariate analysis; cluster analysis; ordination; anthropogenic factors; forest, Hindukush range

Fund project: This work was supported by the Higher Education Commission of Pakistan,

The online version is available at http:// www.springerlink.com

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Corresponding editor: Zhu Hong

Introduction

Chitral District is located mainly in the dry temperate zone of Pakistan (Champion et al. 1965). Elevations range from 1070 to 7708 m a.s.l., creating many local climatic and vegetation zones (Beg and Bakhsh 1974). Although the area is predominately arid, there is wide floristic variety of forest and non-forest vegetation due to the variety of ecological zones (Stewart 1982). Nusser and Dickore (2002) reported that the vegetation of the eastern Hindukush reflects the predominant gradient of decreasing annual precipitation from southeast to northwest with an obvious characteristic of elevation zonation in vegetation spanning more than 4,000 m a.s.l. The eastern Hindukush forms a triangular "ecotone-zone", which delimits the Irano-Turanian, Sino-Himalayan, and Central Asiatic floristic regions. The northern boundary of West Himalayan montane coniferous forests runs through southern Chitral, whereas northern Chitral and the inner valley floors are noticeably treeless (personal observation).

The subalpine and alpine belts are predominately covered by thorn-cushion and dwarf-scrub vegetation, which contains many Irano-Turanian and Pamirean floristic elements (Nusser and Dickore 2002). From west to east, Chitral comprises a region with considerable variation in species composition, apparently reflecting difference in seasonal patterns of rainfall. The plant species provide a wealth of beneficial products that contribute significantly to the quality of life of the local inhabitants (Sheikh and Hafeez 2005; Ali and Qaiser 2009). The study area is represented by six conifer species, *viz*. *Cedrus deodara*, *Pinus gerardiana*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana*, *Juniperus excelsa*, and dominant broad-leaf species *Betula utilis*, *Quercus baloot*, and *Quercus dilatata*. Among the conifers, *Cedrus deodara* is Pakistan's national tree, provides excellent

quality timber, and has great national economic importance. However, these forest species are in poor condition due to anthropogenic disturbances, including illegal cutting, regional land use systems, irrigated crop cultivation, and nomadic livestock husbandry. These factors have considerable impact on the distribution of vegetation types (Khan et al. 2010) and result in the degradation of large areas of land in different elevational belts and sub-regions (Alamgir 2004; Khan et al. 2011a). Numerous recent studies described plant communities with special emphasis on forest vegetation affected by anthropogenic activities in various climatic zones of Pakistan (Nafeesa et al. 2007; Siddiqui et al. 2010; Ahmed et al. 2011; Wahab et al. 2011; Khan et al. 2011b and Shaheen et al. 2011). The Chitral Hindukush range of Pakistan, however, has been studied purely from a phytosociological viewpoint while environmental factors have been ignored. Consequently, a detailed study of the area was needed to assess environmental impacts on vegetation. The main objectives of our study were: (1) to determine the relationship between vegetation and the major environmental variables; and (2) to describe the plant communities in the forests at high mountain elevations, using multivariate techniques.

Materials and methods

Field sampling was conducted during 2008–2010 in Chitral district. Site characteristics, including elevation, slope gradient and slope aspect, were recorded using altimeter, clinometer and compass, respectively. Global Positioning Systems (GPS) were used to determine geographical coordinates. Although, Chitral is a narrow valley with many small tributary valleys, many forest stands were sampled. The criteria for the selection of stands were as follows: (1) limited disturbance and free from severe or recent fires, logging or grazing; (2) area of 2 ha or more, and (3) distant from roads and thus least affected by anthropogenic disturbance.

The Point-Centered Quarter (PCQ) method of Cottam and Curtis (1956) was used for sampling forest tree species to quantify vegetation composition, while 1.5-m circular plots at each PCQ point were regularly placed to sample understory vegetation. In each stand, 30 PCQ points were sampled along a transect (Ogden and Powell 1979). Thirty forest stands were sampled. This sampling procedure was recommended over systematic and random sampling by Bourdeau (1953) and Orloci (1975). An adequate number of sampling points is required for accurate estimation of density of individual species (Cottam et al. 1953). To increase the sample size for relative density, we recorded a second nearest tree (Ogden and Powell 1979). The distance was not measured for this tree but DBH (diameter at breast height) was recorded. Diameters of trees (≥10 cm DBH) near sampling points and transects were also measured to increase sample size. A species list with a frequency table for understory plants was made using circular quadrats (1.5-m diameter) at each PCQ point. In some cases, this included tall shrubs and small trees. Lower plants were largely ignored but the widely distributed Pteridophytes were recorded. Saplings and seedlings of conifers (≤10 cm, ≤5 cm DBH) were counted in each plot and the their densities were calculated for every stand.

Herbarium specimens

In the field, voucher specimens of unidentifiable plants as well as representative identified species were collected. Over 125 specimens and duplicate samples were pressed, and deposited in the Laboratory of Dendrochronology and Plant Ecology, Federal Urdu University Herbarium. All specimens were later identified or revised with the help of various floras including the flora of Pakistan (Nasir and Ali 1972; Ali and Qaiser 2009) and by consulting the Herbaria of the University of Karachi and Federal Urdu University. All specimens thus identified were deposited at the herbarium of Plant Ecology Laboratory of Federal Urdu University Karachi.

Data analysis

Quantitative data for trees, shrubs, herbs and pine seedlings and saplings were summarized following Mueller-Dombois & Ellenberg (1974). All point-to-plant distances were totaled, averaged and mean distances were computed. The mean area of ground surface occupied by an individual tree was obtained by taking the square of the mean distance. The vegetation was quantitatively analyzed for relative frequency, relative density, density per hectare, basal area ($m^2 \cdot ha^{-1}$) and importance value (IV) following Curtis & McIntosh (1950). Relative density is the number of individua1s of a tree species expressed as a percentage of the total number of individua1s of a1l species recorded. According to Brown and Curtis (1952), importance value gives more information about the species than any other single attribute and reflects the ecological importance of the species in a stand. Therefore, the relative values of frequency, density and basal area were summed to yield an Importance Value Index (IVI) for a particular stand. Every species was ranked according to its importance value and the species with the highest importance value in the stand was considered the dominant species. Communities were named on the basis of the first two dominant species.

Data were analyzed using the package PC-ORD for windows, version 5.10 (McCune and Mefford 2005). Although data on the frequency, density and basal area of plants were collected using the point centered quarter method (trees) and quadrat method (understory), we used importance value indices for tree species in multivariate analyses i.e., (1) Agglomerative clustering method (Ward's clustering). (2) Divisive method e.g. TWINSPAN (Two way indicator species analysis) and (3) Detrended correspondence analysis (DCA). IVI data were used because IVI is a good index for summarizing vegetation characteristics, ranking species, and management and conservation practices. It reflects the degree of dominance and abundance of a given species in relation to other species in the area (Kent and Coker 1992; Baruch 2005; Song et al. 2009). The frequency of species in the understory vegetation was divided into 5 classes following the categories proposed by Tansley and Chipp (1926) and Tansley (1946). These classes were based on sampled frequency, as follows: (1) 1%–20%, Rare, (2) 21%–40%, Occasional, (3) 41%–60%, Frequent, (4) 61%–80% Abundant and (5)

81%−100% very abundant.

Cluster analysis and ordination were applied to two data sets for each of thirty stands. These data sets were (1) a set of tree data; and (2) the corresponding environmental data set (Shaukat and Siddiqui 2005). Rare species (i.e. those which occurred in 3 or fewer stands) were excluded from analysis to avoid distortion of the results of cluster analysis and ordination (Shaukat 1989; Shaukat and Siddiqui 2005; McCune et al. 2000; Timilsina et al. 2010). Measured vegetation composition and physiognomy, environmental variables and derived nutrient index data were summarized for each vegetation type. Subsequently, the descriptive statistics, including both physiographic site variables and biophysical parameters, were reported as averaged for each group identified by cluster analysis.

Ordination

Detrended correspondence analysis (DCA) (Hill and Gauch 1980) was used to examine the pattern of vegetation composition and structure across the study area while ecological species groups or vegetation types were exposed by means of cluster analysis. DCA was chosen because this technique is geared to ecological data sets, and secondly some problems associated with other ordination methods such as correspondence analysis (CA) are corrected in DCA analysis. However, correspondence analysis (CA) and principal component analysis (PCA) were also preformed for the purpose of comparison.

Soil analysis

Three soil samples were collected at randomly selected locations within each stand and then pooled to obtain a composite sample for each stand. The litter from the surface was removed and soil samples were individually mixed well before use. Soil samples were dug from 0−30 cm depths using a soil auger and then air-dried. About 500 g of soil from each sample was placed in a polyethylene bag, labeled and brought to the laboratory. Air dried (25−30 ºC) soil was passed through a 2-mm sieve and analyzed for physicochemical characteristics. Soil pH was measured in a 1:5 soil: water paste using a Dynamic digital pH meter (Model sension, TM 105) as soon as possible after collection from the field. Total dissolved salts, salinity and conductivity were detected using a Multi-parameter meter.

Maximum water holding capacity (MWHC) was determined following Keen (1931) while soil organic matter (SOM) was determined by the method of Jackson (1958). Total Nitrogen (N) was determined according to Bremner (1965) using the Kjeldahl method and total Phosphorus (P) was estimated following the method of Bingham (1949). Exchangeable Potassium (K^+), Magnesium (Mg^{2+}) and Sodium (Na^+) were determined by using a Jenway (PFP7) Flame Photometer, following the methods outlined by Pratt (1965), and Peech & English (1944).

Statistical analysis

Environmental variables were tested for significance using Cluster Analysis (CA) and Ordination. The variables test for group differences in Cluster Analysis (CA) and correlation with ordination axes included: Elevation (Elev), Slope gradient (Slope), Aspect and Canopy cover. Slope gradients were segregated into 4 classes *i.e.* gentle (0−15°), moderate (16−30°), steep (31−45°), very steep (46−60°), aspect into eight classes (N, NE, E, SE, S, SW, W and NW) and canopy cover into three classes (open, moderate, and closed). These Aspect and Canopy cover groups were converted into ordered scale variables for quantitative analysis (for example, North=1, West=2, South=3 and East= 4, NE=5, SE=6, SW=7, NW=8, and Open=1, Moderate=2 and Closed=3). Palmer (2005) suggested using ordered scale variables for aspect because this method expedites later interpretation of results as compared to simple ranking. Analyses of variance (ANOVA) and multivariate statistics (Hotelling T^2) were used for comparison among groups while correlation and regression analyses were employed in the interpretation of ordination. Excel, SPSS statistical package and a program HOTELLING developed by one of us (SSS) in C^{2+} were employed for statistical analysis.

Results

Classification of tree vegetation data

The dendrogram derived from the cluster analysis using Ward's agglomerative method is given in Fig. 1. The groups were extracted at the 50% information level equivalent to 4×10^4 Euclidean distance. This resulted in six groups while two stands (3, 4) remained as isolated individuals.

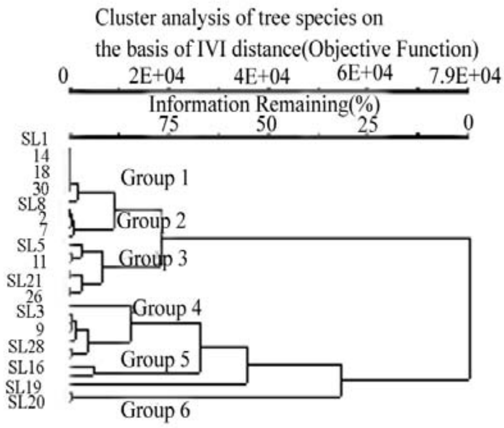

Fig. 1 Dendrogram obtained by agglomerative Ward's cluster analysis showing 30 stands of tree species representing six major groups (Community types) in the study.

Group I- *C. deodara* and *P. wallichiana* community

Group 1 consisted of 7 stands dominated by *Cedrus deodara* (I.V. 97.99%), while *P. wallichiana* was the only subordinate species in the tree stratum with very low importance value (2.20%). The understory vegetation comprised 24 species, of which *Artemisia*

maritima and *Cedrus deodara* were abundant, while *Ferula assafoetida* and *Rosa webbiana* were frequent species. *Carum bulbocastanum, Fragaria vesca*, *Echinops cornigerus*, *Carum carvi*, *Ranunculus muricatus*, *Sambucus wightiana*, *Urtica dioica,* and *Verbascum thapsus* were occasional species with average frequency ranging from 20%–40%. Among other species *Daphne oleoides*, *Capparis spinosa*, *Malva neglecta*, *Oxalis corniculata*, *Pinus gerardiana*, *Rumex dentatus*, and *Vicia bakeri* were rare species with average frequency ranging from 6.33%–20%.

Group II- *C. deodara* and *P. gerardiana* community

This group comprised four stands and was dominated by *Cedrus deodara* with an average importance value of 72.74%. *Pinus gerardiana* was also well distributed in comparison to other conifer species with an importance value of 16.19%. Two other conifers, namely *Juniper excelsa* and *Pinus wallichiana,* also occurred with low importance value. The understory was composed mainly of *Cedrus deodara* and *Artemisia maritima* at highest frequency. However, *Rosa webbiana* was frequent while *Gegea pseuduumbellata, Berberis lycium, Pinus gerardiana*, *Pistacia khinjuk*, and *Verbascum thapsus* occurred occasionally (Table 1). *Andropogon* sp., *Arenaria griffiithii*, *Cappiris spinosa*, *Berberis psedumbellata*, *Carum balbocastanum*, *Chenopodium foliosum*, *Cichorium intybus*, *Daphne oleoides*, *Fraxinus xanthoxyloides*, *Habenaria aitchisonii*, *Malva neglecta* and *Thymus serpyllum* were rare species of this group.

Table 1. Six groups obtained from cluster analysis of tree species from 30 stands based on the mean importance value of tree species and environmental variable (elevation, slope, aspect and canopy)

Tree species	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE
C. deodara	97.9±2.2	72.7±3.1	60.5±4.3	53.4±2.6	29.8±22	*
P. wallichiana	2.2±00	3.4±2.5	*	*	57.8±9.3	*
P. gerardiana	*	16.1±1.7	1.2±0.78	30.4±5.4	*	*
A. pindrow	*	*	15.58±	7.13±4.5	25.1±6.6	*
P. smithiana	*	*	19.1±3.6	*	*	*
J. excelsa	*	8.4±3.1	*	3.26±00	*	94.5±5.5
B. utilis	*	*	*	*	*	5.19±00
Q. baloot	*	*	0.92±00	15.02±2.8	*	*
Q. dilitata	*	*	0.8±00	3.56±1.0	*	*

Note: * is absence of species in different groups.

Group III- *C. deodara* and *A. pindrow* community

This group was dominated by *Cedrus deodara* at average importance value of 60.58%. Two other conifers and two angiosperms were also associated as subordinate species. Among the conifers, *Abies pindrow* and *Picea smithiana* were associated with importance values of 19.12% and 15.58%, respectively. Broad-leaved tree species i.e. *Quercus baloot* and *Quercus dilatata* showed low abundance in this group.

The understory vegetation comprised forty three species. Among these species *Cedrus deodara* was abundant, while *Artemisia parviflora*, *Astragalus anisacanthus*, *Plantago lanceolata* and *Rosa webbiana* were frequent. *Berberis psedumbellata*, *Epilobium angustifolium*, *Gegea pseduumbellata*, *Parrotiopsis jacquemontiana*, *Pinus gerardiana*, *Silene vulgaris* and *Verbscum thapsus* were occasional species. *Ephedera gerardiana*, *Fragaria vesca*, *Geranium rotundifolium*, *Malva neglecta*, *Pinus wallichiana* seedling, *Salix tetrasperma* and *Sedum multicaule* were rare.

Group IV- *C. deodara* and *P. gerardiana* community

Six tree species including gymnosperms and angiosperms characterized this group. Among conifers, *Cedrus deodara* was the dominant tree species with highest IV of 53.41%. *Pinus gerardiana* was co-dominant with IV of 30.46%. *Juniperus excelsa* showed very low importance value. Among the broad-leaved species, *Quercus baloot* showed IV of 15.02%, while the importance value of *Quercus dilatata* was very low. Thirty-one understory species were recorded in total. Among them, *Cedrus deodara*, was abundant at 61.42% frequency. Frequent species were absent in this group. *Delphinium ajcis*, *Fragaria vesca* and *Impatiens edgeworthii* were occasional species. A number of species occurred in the lowest frequency range (1%–20%). Among these *Artemisia maritima*, *Arenaria griffiithii*, *Berberis lycium*, *Oxalis corniculata*, *Micromeria biflora* and *Rumex dentetus* were common in other groups.

Group V- *P. wallichiana* and *C. deodara* community

Group V was small, represented by only two stands, and consisted of three conifer species. Among these, *Pinus wallichiana* was the leading dominant with IVI of 57.82%, whereas, *Cedrus deodara* was co-dominant at 29.82%. Beside these species, *Abies pindrow* occurred with comparatively low importance (Table 1). Understory species were mainly *Cedrus deodara, Pinus wallichiana*, *Sambucus wightiana*, *Pedicularia rotundata*, *Impatiens brachycentra* and *Echinops cornigerus*. Frequencies of these species ranged from 41%–60%. *Fragaria vesca*, *Indigofera heterantha* and *Ormoeterum tuberosum* were occasional species. *Abies pindrow*, *Artemesia maritima*, *Berberis lycium*, *Carum carvi*, *Delphinium ajcis*, *Impatiens edgeworthii*, *Micromeria*

biflora, *Quercus baloot* and *Pinus wallichiana* occurred at frequencies ranging from 4%–20%.

Group VI- *J. excelsa* and *B. utilis* community

This group was represented by a small number of stands. Two species, one gymnosperm and one angiosperm, were recorded (Table 1). *Juniperus excelsa* was the dominant tree species with 94.5% of IV while the broad-leaf species *Betula utilis* occurred at low abundance (5.19%). Extremely poor ground flora was observed for this group. Twenty five understory species were recorded, among which *Artemisia maritima*, *Artemisia parviflora, Berberis pseudumbellata*, *Carum bulbocastanum*, *Rosa webbiana*, *Rumex dentatus*, *Rumex hastatus*, *Silene vulgaris* and *Juniperus excelsa* were abundant. *Aconitum chasmanthus, Aconitum leave,* and *Verbascum thapus* were occasional, while *Cichorium intybus*, *Dephne oleoides*, *Inula grandiflora*, *Sedium multicule* and *Thymus serpyllum* were rare.

Beside these six groups, two groups were represented by single stands (Fig. 1). Stand 3 was dominated by *Pinus gerardiana* (IV. 69.21%) with *Quercus baloot* co-dominant with 30.79% of importance value. The understory vegetation was comprised of *Artemisia maritima*, *Artemisia parviflora*, *Caragana ambuigua*, *Pinus gerardiana, Rosa webbiana*, *Pistacia khinjik*, *Fraxinus xanthoxyloides*, *Hippohae rhamnoides*, *Lonicera quinquelocularis*, *Daphne oleoides* and *Thymus serpyllum*. Stand 4 was also isolated in the dendrogram. It was a pure stand of *Quercus baloot* (IV 100%). The understory was comprised of *Artemisia maritima*, *Artemisia parviflora*, *Arenaria griffiithii*, *Caragana ambuigua*, *Verbascum thapsus*, *Pistacia khinjuk*, *Daphne oleoides*, *Fraxinus xanthoxyloides*, *Hippohea rhamnoides*, *Indigofera heterantha*, *Thymus serpyllum* and *Prunus avium* (seedlings).

Environmental characteristics of the groups

The average elevation of group I was 2,450 m, second lowest of all groups (Table 2). The average slope of stands was medium (30°), while aspect was generally East, West, North, North West, and North East. Canopy cover for this group was moderate. The soil organic matter was highest among all groups while concentrations of Ca^{2+} and Mg^{2+} were higher than for other groups. K^+ content was low. Among edaphic variables, soil pH was lowest (i.e., acidic) while salinity was high with medium conductivity. The maximum water holding capacity of soil was of medium order for this group.

Table 2. Mean values of environmental factors obtained by cluster analysis on the basis of IVI of tree species

Factors	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Isolated 7	Isolated 8
	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE
Elevation	2450±96	2589±154	2454±69	2240±73	2559±215	2742±22	2479±00	1920±00
Slope	30±3.8	26±2.5	33±5.2	38±3.4	30±1.0	19±1.0	42±00	15±00
Aspect	3.85±1.0	3.7±1.0	4.5±1.0	3.1±1.0	2.5±1.5	5.5±0.5	1±00	7±00
Canopy	1.45±0.2	1.5±0.28	1.28±0.1	1.16±0.16	2.5±0.5	1.0±00	1±00	1±00
Organic matter (%)	5.9±0.93	4.9±0.80	5.0±0.59	4.5±0.40	4.0±0.22	5.6±0.05	5.5 ±00	3.9±00
Ca (%)	2.1±0.81	0.30±0.08	0.85±.23	1.5±0.78	0.38±0.1	0.3±0.14	0.34±00	0.41±00
Mg (%)	0.62±0.16	0.37±0.09	0.55±0.06	0.55±0.04	0.71±0.07	0.56±0.04	0.18±00	0.46±00
Na (%)	0.68±0.18	1.05±0.31	0.4±0.09	0.56±0.01	0.51±0.03	0.49±0.04	1.36±00	0.97±00
K (%)	1.47±0.36	1.67±0.22	1.70±0.30	1.35±0.1	2.19±0.1	2.22±0.11	1.88±00	1.66±00
N (%)	0.36±0.17	0.49±0.37	0.16±.04	0.23±0.13	0.06±50.02	0.33±0.08	0.32±00	0.29±00
pH	5.7±0.16	5.8+0.26	6.2+0.17	6.0+0.13	6.4+0.09	6.5+0.05	5.8±00	5.6±00
Water holding capacity (%)	49.3±3.2	51.2±4.8	54.2±3.5	44.9±3.0	46.9±5.0	43.1±9.4	41.3±00	40.9±00
Salinity (%)	0.3±0.06	0.12±0.02	0.210±.03	0.210±.04	0.25±0.15	0.25±0.1	0.1±00	0.3±00
Conductivity ($mS \cdot cm^{-1}$)	280±41.5	220±34.1	372±38.4	344±49.5	446±144	272±11	223±00	156±00
total dissolve salts ($mg \cdot L^{-1}$)	164±18.9	105±11.3	205±27.5	186±28.4	27±351.5	197±22.3	122±00	96±00

Group II stands were generally located at high elevation (average 2589 m) while slopes were moderate (26°) and second lowest. The stands were generally located on South, North, and West facing slopes. Canopy for this group was medium. Among the soil nutrient factors, organic matter content was medium, while the concentrations of Ca^{2+} and Mg^{2+} were low, though K^+ content was medium. Total nitrogen content for the group was highest. Soil pH and conductivity were both low. The maximum water holding capacity was second highest for this group.

Group III, occurred at second lowest elevation (average 2454 m) and occurred on steep slopes (33°) facing mostly North East, West and North aspects. Canopy was the highest rating of all groups. Soil organic matter was moderately high while the nutrients Ca^{2+}, Mg^{2+} and K^+ were found in moderate concentrations (Table 4). Total nitrogen for this group was second lowest among all groups. Soil pH and conductivity were both high. Group III soils had highest maximum water holding capacity.

The stands of Group IV were located at an average elevation of 2240 m, lowest among all groups. Comparatively steep slopes (38°) were recorded for this group. Canopy was of moderate order. Soil organic matter was second lowest among all groups. Ca^{2+}, $Mg^{2+}$and K^+ were found in moderate concentrations, while total nitrogen was second lowest of all groups. Soil pH and salinity were of medium order. Conductivity was highest of all groups.

Stands of group V were located at average elevation of 2559m, on moderate slopes (30°). Aspect was fewer steps than previous

IV group and canopy was generally of moderate order. The value of soil organic matter was lowest among all groups. Concentrations of Ca^{2+}, and K^{+} were moderate, while the concentration of Mg^{2+} was highest. Extremely low concentration of nitrogen was recorded for this group. Soil pH was acidic for this group with highest conductivity of all groups.

Stands of group VI were recorded at highest elevation (2,742 m) and on moderate slopes (19°). This value of slope was lowest of all groups. The stands were on West and Southwest aspects with open canopies. Soil organic matter was moderate. Mg^{2+} and K^{+} concentrations were high, while the concentration of Ca^{2+} was lowest of all groups. Soil pH was slightly acidic with moderate conductivity (Table 2). Maximum water holding capacity was lowest among all groups.

The isolated groups (stands) were located at elevations of 2,479 m (Stand 3) and 1,920 m (Stand 4) while slopes were relatively steep (42°) and gentle (15°), respectively. Stands were facing North with open canopies. Organic matter was medium for Stand 3 while Stand 4 was lowest of all groups. Concentrations of $Mg^{2+}$and Ca^{2+} were also of medium order for these groups. The value of K^{+} was low at Stand 3 as compared to Stand 4. Soil pH was acidic with low conductivity. Salinity was very low at Stand 4 compared to the prior Stand 3.

Univariate analysis of variance (ANOVA)

Using Ward's clustering strategy, six main groups and two individuals (isolated stands) were recognized. The individual environmental variables corresponding to the six groups were analyzed using univariate analysis of variance (ANOVA) (Table 2). Among topographic variables, elevation and canopy cover were significant (F=2.065; p < 0.10 and F=2.573; p < 0.05, respectively), while there were no significant differences by slope or aspect. Edaphic variables, i.e. maximum water holding capacity, soil pH, salinity and conductivity showed non-significant differences in group means (Table 3). However, total dissolved salts showed significant difference (F = 2.612; p <0.01).

Hotelling T^2 Test

Hotelling T^2 test, a multivariate statistic, was applied for the comparison of groups derived from Ward's clustering technique on the basis of mean vectors of environmental variables. The three categories of environmental variables i.e. topographic, edaphic and soil nutrients were compared between pairs of groups with respect to the first set of variables. Groups 1 and 2 were significantly different (F=3.4, df_1=7, df_2=4, p <0.05) while the mean vectors for groups 1 and 3 and 2 and 3 were not significantly different. Edaphic variables were similar for groups 1 and 2 (F=0.9, df_1=7, df_2=4, Ns), groups 1 and 3 (F=0.1.5, df_1=7, df_2=7, Ns) and groups 2 and 3 (F=0.1.33, df_1=4, df_2=7, Ns),(Ns is non significant.). None of the nutrient concentrations in soils differed between groups.

Ordination

DCA Ordination of tree vegetation data set

Correlations between forest vegetation stands and their corresponding environmental variables were evaluated by DCA ordination. DCA ordination was based on the importance value of tree species while the interrelationship between ordination axes and the individual environmental variables was computed by correlation coefficients.

Stand ordination

The ordination plot of axes 1 & 2 showed a more or less continuous pattern (Fig. 2–4). The vegetation continuum appears to be a function of altitude and the slope gradients that were both correlated with the first ordination axis (see below for the correlation of ordination axes with environmental factors). However, the five groups derived from Ward's cluster analysis can be superimposed neatly on the 2-D DCA ordination (Fig. 2) with the exception of group IV, which overlaps with group II on DCA ordination axes 1 and 2, while group V overlaps with group IV on ordination axes 1 and 3. The other groups exhibited no overlap.

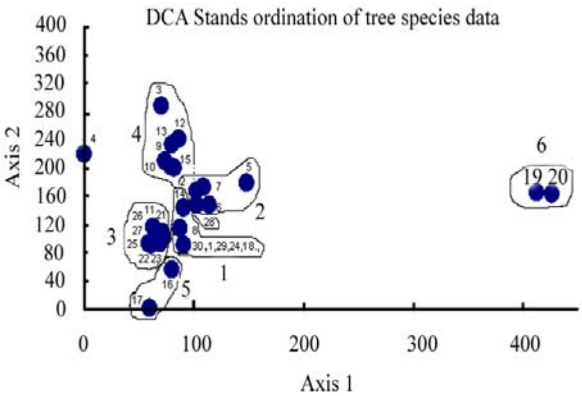

Fig. 2 DCA among axis 1 and 2 of tree vegetation data based on IVI. The groups derived from Ward's cluster analysis are superimposed on 2-D ordination axis

The distribution pattern of stands in two-dimensional ordination (axes 1 and 2) showed a cluster of different stands in the left middle upper and lower sides in the ordination space, while Group VI was located towards the right of the ordination configuration. Stand 4 was isolated in the cluster analysis and was placed on the extreme left side of the ordination. The ordinations of axes 1 and 3 and axes 2 and 3 exhibited an almost continuous distribution pattern of stands across the ordination planes (Fig. 3 and 4). Six main groups were separated on the basis of highest importance value. All 7 stands in Group I were dominated by *Cedrus deodara*. This group was monospecific. Group II was comprised of four stands designated as *Cedrus deodara* dominant groups, while, *Pinus gerardiana* was also fairly abundant. Group III, was comprised of seven stands dominated by *Cedrus deodara*. *Abies pindrow* and *Picea smithiana* were subordinate species of Group III. In Group IV, seven stands (stand 3, 9, 10, 12, 13, 15, and 28) were composed of *Cedrus deodara* as the dominant species, whereas *Pinus gerardiana*, *Juniperus excelsa*,

Quercus baloot and *Quercus dilatata* were associate species. Groups V and VI were small groups comprised of two stands (stand, 16 and 17 and 19 and 20). These groups were dominated by *Pinus wallichiana*, and *Juniperus excelsa*. Associated species were *Abies pindrow*, *Cedrus deodara* and one broadleaf angiosperm species *Betula utilis*.

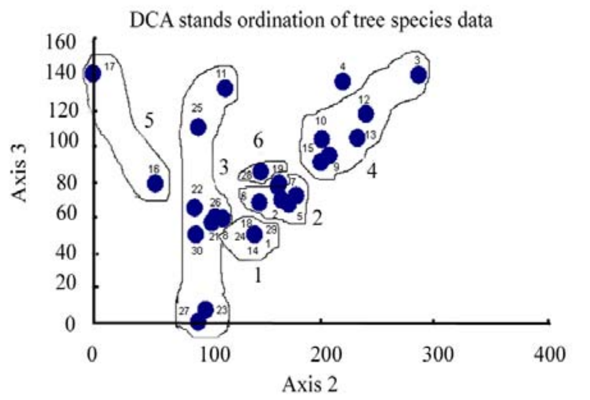

Fig. 3 DCA ordination of stands (tree vegetation data) on axes 2 and 3

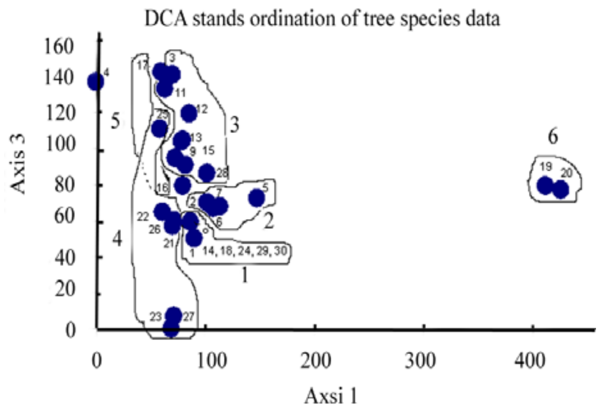

Fig. 4 DCA ordination of stands (tree vegetation data) on axes 1 and 3

Correlation of ordination axes with environmental variables

The correlation of DCA-Ordination axes with environmental variables is presented in Tables 3–5. Ordination axis 1 was positively correlated (Fig. 4) with elevation ($p < 0.05$) and negatively correlated with degree of slope ($p < 0.01$), while aspect, pH, maximum water holding capacity, salinity, conductivity, soil organic matter, Calcium (Ca^{2+}), Magnesium (Mg^{2+}) Sodium (Na^{+}) and Nitrogen (N) showed no significant correlation.

Table 3. Correlation coefficient between topographic factors and DCA ordination axis. DCA stands ordination based on the data of importance value index of tree vegetation

No.	Variables	Axis 1	Prob. Level R	Axis 2	Prob. Level R	Axis 3	Prob. Level
1	Elevation	0.359	p<0.05	-0.334	p<0.05	-0.2762	Ns
2	Slope	-0.2999	p<0.01	0.0597	Ns	0.2974	p<0.01
3	Aspect		Ns		Ns		Ns

Notes: Ns is non significant and prob.

Axis 2 was positively correlated with elevation ($p < 0.05$), pH ($p < 0.01$) magnesium ($p < 0.05$), sodium ($p < 0.01$) and potassium ($p < 0.01$). With respect to topographic and edaphic variables, axis 3 exhibited significant correlations with slope ($p < 0.01$) and maximum water holding capacity ($p < 0.05$). Magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^{+}) exhibited positive correlation with ordination axis 3 at $p < 0.01$ and $p < 0.05$ probability level s , respectively.

Table 4. Correlation coefficient among edaphic factors and DCA Axis 1, 2, 3

No.	Variables	Axis 1	Prob. Level R	Axis 2	Prob. Level R	Axis 3	Prob. Level R
1	pH	0.2091	Ns	-0.284	p<0.01	-0.044	Ns
2	MWHC	-0.1027	Ns	-0.114	Ns	-	p<0.05
3	Salinity	0.0774	Ns	-0.143	Ns	-	Ns
4	Conductivity	-0.134	Ns	-0.3158	Ns	-	Ns

Notes: Ns is non significant and prob.

Table 5. Correlation coefficient among organic matter, soil nutrients and DCA axis 1, 2, 3

No.	Variables	Axis 1	Prob. Level R	Axis 2	Prob. Level R	Axis 3	Prob. Level R
1	Org. matter	0.1148	Ns	-0.0078	Ns	-0.2949	p<0.01
2	Ca	-0.1316	Ns	-0.246	Ns	-0.3481	p<0.05
3	Mg	0.0544	Ns	0.3429	p<0.05	-0.2704	p<0.01
4	Na	-0.0865	Ns	0.2767	p<0.01	-0.0339	Ns
5	K	0.2031	Ns	-0.3057	p<0.01	-0.4201	p<0.05
6	N	0.0739	Ns	0.0209	Ns	-0.1524	Ns

Notes: r is correlation coefficient, Ns is non significant and prob. Level is Probability level.

Discussion

Multivariate analysis

The vegetation of the study area was fairly diverse and typical of much of the dry temperate area of the country (Champion et al. 1965; Alamgir 2004). Forest vegetation types were classified using cluster analysis. A quantitative method of analysis was used for objective categorization (Okono 1996). In general, multivariate analysis was exceedingly useful in exposing the underlying group structure and the major prevailing gradients in the data structure.

The two clustering strategies employed, namely the agglomerative clustering technique developed by Ward (1963) and the divisive Polythetic technique of TWINSPAN, though conceptually quite different, when applied to 30 forest stands yielded closely similar results in terms of emerging group structure inherent in the vegetation. However, the results of TWINSPAN divisive polythetic method are not presented here due to the similarity of results. The thirty stands were classified into 6 groups

(community types) by Ward's agglomerative method of tree species vegetation associated with different topographical, edaphic and soil nutrient regimes. Each community type is characterized by a dominant, diagnostic species as well as by associated species which had high constancy or relative abundance in the group. The hierarchical cluster analysis demarcated six distinct groups and two isolated groups consisting of pure and mixed populations of tree species. Not surprisingly, the two objective classification techniques proved to be useful in classifying the vegetation that demonstrated well-marked association with certain environmental (topographic and edaphic) variables and the two techniques yielded more or less similar results providing consistency in pattern.

The groups resulting from Ward's cluster analysis were either dominated by a single species (e.g., *Cedrus deodara*) or two conifer species in various combinations. In some cases broad-leaved species such as *Quercus baloot*, *Quercus dilatata* and *Betula utilis* occurred in combination with the conifers. The groups showed correlation with edaphic factors, such as pH, Mg^{2+}, Ca^{2+} and K^{+} and topographic factors including elevation, degree of slope and aspect. Most of the identified vegetation groups had characteristics shared with other moist and dry temperate forests of Pakistan and even in neighboring countries (Ahmed et al. 1990, 1991; Malik et al. 1993, 1996, 2004; Ahmed et al. 2006; Wahab et al. 2008; Ajaib et al. 2009; Ahmed et al. 2010). *Cedrus deodara* was the dominant tree species of the study area. Of six groups (communities) it was dominant in four groups, while in one group, it was co-dominant with *Pinus wallichiana*. *Cedrus deodara* and *Pinus wallichiana* community types have also been recorded by Wahab et al. (2008, 2011) in their study on the vegetation of District Dir and Afghanistan border. Similarly Siddiqui et al. (2010) reported this community from the moist temperate area of Pakistan.

Cedrus deodara was also observed in association with *Abies pindrow* and *Picea smithiana*. These community types were reported by Ahmed et al. (2006) from moist temperate parts of the country. Some others (e.g.), *Pinus gerardiana* community and *Juniperus excelsa* community type were recorded by Ahmed et al. (1990, 1991) from Balochistan province. However, the communities (groups) recorded in the present study are considerably different, particularly with respect to species association. *Pinus gerardiana*, *Juniperus excelsa* are typical tree species of dry temperate areas that group with the broad-leaved *Quercus baloot* and *Betula utilis* in the present study. This could be due to the differences in geomorphology and water availability in the two areas.

DCA Ordination

The results of DCA ordination strongly supported the results of cluster analysis as the groups disclosed could readily be superimposed on the two dimensional DCA ordination configurations. Greig-Smith (1983) and Shaukat (1985) concluded that the two basic techniques, *viz.* classification (clustering) and ordination, are complementary to each other though fundamentally applied for different purposes.

According to Barton (1993), the primary objective of plant ecology is to understand the factors controlling local distribution of plant species and composition of the plant communities. Plant communities change gradually along environmental gradients (Jin et al. 2008; El-Bana and Al-Mathnani 2009). Therefore, understanding of the distribution pattern of vegetation along with the causal factors in particular areas is important (Weiser et al. 1986; Stephenson 1990; Endress and Chinea 2001; Bai et al. 2004). In the present study, DCA ordination of tree stands depicted a vegetation continuum that appears to be a function of elevation and slope as both the topographic factors correlated with the first ordination axis. Thus it can be argued that topography is the principal controlling factor in vegetation growth. Soil and precipitation play only a secondary role at the scale of hill slopes as suggested by earlier works (O'Longhlin 1981; Wood et al. 1988; Dawes and Short 1994).

Hill and Gauch (1980) and McCune and Grace (2006) suggested that DCA is capable of yielding at least one basic gradient associated with the vegetation. However, in the present study the ordination axes correlated with more than one gradient (altitude and slope). According to Titshall et al. (2000), elevation and slope are the main topographic factors that control the distribution and patterns of vegetation in mountain areas. However, among these factors, elevation is most important (Day and Monk 1974; Busing et al. 1992) because elevation along with slope in many respects determines the microclimate and thus large-scale spatial distribution and the vegetational pattern (Day and Monk 1974; Johnson 1997; Marks and Harcombe 1981; Allen and Peet 1990; Busing et al. 1992). Similar results were reported by Song et al. (2009) for vegetation of the Yellow River Delta, Eastern China. They found that the vegetation distribution pattern was mainly related to elevation, and other environmental variables. However, the undetermined variation was attributed to biological and stochastic causes and other environmental factors that remained unrecorded. However, our results are directly comparable.

The results of univariate comparison (single factor ANOVA) and multivariate comparison (Hotelling's T^2) also established some relationships with topographic, edaphic and soil nutrients. However, both analyses confirmed that groups derived from Ward's clustering strategy showed significant differences with different environmental variables particularly with elevation. Similar results were reported by Ahmed et al. (2011) Siddiqui et al. (2011) and Khan et al. (2011c) in the vegetation from moist and dry temperate areas of the country. Our results to a great extent support their conclusions with regard to vegetation-environmental relationships. In this respect, all studies showed a marked correlation of one of the ordination axis (usually the first one) with elevation, i.e., an elevation gradient was common in these studies.

Many authors have found that the species distribution reflects the effect of several factors at different scales (El-Bana and Al-Mathnani 2009). However, Ricklefs (1990) and Ringrose et al. (2003) demonstrated that topography and soil are considered to exert influences on the plant distribution at regional and landscape levels. Among the edaphic and soil variables, Mg^{2+}, K^{+} and N^{2+} are the factors of environmental significance along DCA

ordination axes. But these factors contributed not more than 0.054%, 0.20% and 0.073%, respectively, of the total variation along ordination axis 1. This means that other factors, not included in this analysis could be more effective. The principal reason for weak or no correlation with many of the edaphic and soil variables i.e. pH, water holding capacity, salinity, conductivity, Ca, Mg, Na, P, K and organic matter seem to be disturbance of vegetation, primarily owing to legal or illegal logging, cutting of trees and grazing of domestic animals. Siddiqui et al. (2010) presented similar results among the edaphic and soil variables along DCA ordination axeis. On the other hand, Khan et al. (2011) reported that none of the measured environmental variables measured explained the distribution pattern of the vegetation in the site ordination and concluded that past disturbances, particularly the anthropogenic disturbances are mainly responsible for the different community types. Shaltout et al. (2008) reported that some anthropogenic factors (e.g. overgrazing by domestic animals and overcutting of woody plants) play an important role. Approximately 60% of the forest in Pakistan is degraded mainly due to overgrazing and overcutting (Baig et al. 2008). Therefore, the examination of anthropogenic disturbances and other biotic effects could be important. This needs further research focusing on these variables and their role in determining the composition of plant communities.

Mostly the forest vegetation in the study area is distributed between elevations of 1,450 m and 2,700 m a.s.l. It is additional support to the opinion that elevation is the main controlling factor in vegetation growth, while slope also significantly affected vegetation development. *Cedrus deodara*, *Pinus wallichiana* and *Abies pindrow* were also recorded on moist sites of dry temperate areas. In other words, the most robust vegetation growth is associated with the shady side of the mountain where less evapotranspiration (ET) is expected. The above mentioned species except *Cedrus deodara* are typical moist temperate species as reported by Champion et al. (1965) and Ahmed et al. (2006). Ahmed et al. (2010) reported that *Cedrus deodara,* forests, distributed from dry to moist temperate regions in the Hindukush and Himalayan region at 1650–2927 m elevations, are predominately controlled by moisture and altitudinal gradients. This suggests that *Cedrus deodara* has wide ecological amplitude. In some stands *Cedrus deodara* was associated with *Pinus gerardiana* and *Juniperus excelsa*, indicating typical dry temperate conditions while in the other stands *Picea smithiana* and *Abies pindrow* were the associated species, indicating ecotonal zone between dry and moist temperate areas.

Ecologists have long noted and studied the tendency of plant communities to change over time (Luken 1990). Ecological succession is a fundamental concept in ecology; which refers to more or less predictable and orderly changes in the composition or structure of an ecological community (Barbour et al. 1987). Many factors such as earthquakes, landslides, storms, fire can initiate succession. Many species such as *Juniperus excelsa*, *Quercus baloot*, *Quercus dilitata*, *Betula utilis* and *Pinus gerardiana* are disturbance-tolerant species in the present study sites due to anthropogenic disturbances (overgrazing, over-logging and cutting). These overriding factors responsible for poor plant community structure were reported by many researchers (Beg 1974; Khan 1978; Hussain et al. 2007; Khan et al. 2010) and could be considered for the investigation of ecological succession in future.

The above mentioned species are used for multiple purposes, including timber, fuelwood and for fencing purposes. Connell & Slatyer (1977) suggested that some species are specialized to exploit disturbances that create large gaps in forest canopies. However, Turner et al. (1992) stated that a disturbance regime may be quite complex and it is not easy to capture all the aspects of this complexity. Canham and Loucks (1984) added that forests can be affected by fires and severe wind, while Knight (1987) concluded that coniferous forests are influenced by the interaction of parasites and lightning. Franklin and Forman (1987) demonstrated that forest cutting patterns may alter susceptibility to catastrophic wind throw. However, these disturbances are not reported by any worker from the study area, where excessive timber harvest and livestock grazing are considered the primary impacts. Size classes also give a clear picture of the disturbance regime but Runkle (1982, 1985) opined that there is no reserve size that can guarantee landscape equilibrium. However, increasing reserve size should decrease the probability of a dramatic shift in landscape dynamics due to a rare disturbance event.

The final or stable community in a sere is the climax community vegetation which in the present vegetation seems to be constituted by *Cedrus deodara*, *Abies pindrow* and *Picea smithiana* dominated communities. It is stated that such vegetation is tolerant to prevailing environmental conditions, having diversity of species and a distinct spatial structure. A number of understory species were associated with the tree species on the forest floor. Forest understory vegetation has long been recognized as relevant to forest management decisions because of its potential to reflect site quality and indicate forest productivity (Cajander 1926; Coile 1938; Daubenmire 1976).

The study of understory vegetation is important because it influences tree regeneration and suppresses growth of desirable tree seedlings, which are major biological and economic concerns (Horsley 1986; Moser et al. 1996; George and Bazzaz 1999). In the present study, most of the understory was dominated by perennial herbs like *Plantago lanceolata*, *Potentilla biflora*, *Aconitum leave*, *Urtica dioica*, *Impatiens edgeworthii*, *Silene vulgaris* and *Micromeria biflora* which show that these vegetation types are fast growing. Connell and Slatyer (1977) confirmed that communities in early stages are dominated by fast growing, well-dispersed species (*r*-selected species) but with the passage of time, these species tend to be replaced by more competitive (K-selected) species. Such long term observations at a single point in space allow researchers to understand both the internal and external forces driving systematic progress in vegetation. We suggest that permanent plot study will be helpful for understanding these long term changes.

Conclusions

1. The application of multivariate techniques (cluster analysis

and ordination) clarified the patterns of vegetation distribution in the study area in quantitative terms that showed marked relationships between certain environmental (topographic and edaphic) variables and gradients.

2. The two objective classification techniques (agglomerative clustering and the divisive polythetic techniques of TWINSPAN) proved to be useful in classifying the vegetation and yielded similar results in terms of underlying group structure inherent in the vegetation.

3. Assessing relationship between plant communities and environmental variables, including edaphic, topographic and biotic factors provided a broader framework for identifying important factors governing the distribution of vegetation types, compared with those studies that focus on physical landscape variables alone.

4. Mixed coniferous and broad leaved forests management must involve the integrated approach of the entire ecosystem and the components should not be treated in isolation or as units because of the existence of multiple interactions between biotic and abiotic components. The components considered separately do not represent the holocoenotic nature of the environment.

5. Understanding relationships between environmental variables and vegetation distribution in the area have great applications in the management of coniferous and broad leaved forest ecosystems.

Acknowledgments

The authors are grateful to the Higher Education Commission of Pakistan for providing financial support. They also thank the Divisional Forest Officer (DFO) and Protected Area Manager (PAM) of Gol National Park (GNP) in Chitral for providing relevant literature and accommodation facilities. The authors are also thankful to Dr. Jonathan Palmer, Gondwana Tree-Ring Laboratory, New Zealand for providing valuable comments and suggestions that improved an earlier version of the manuscript.

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